Calendar No. 873

100TH CONGRESS
2d Session

SENATE

REPORT
100-457

RENEWABLE ENERGY/FUEL CELL SYSTEMS INTEGRATION ACT OF 1988

AUGUST 5, 1988.—Ordered to be printed

Mr. JOHNSTON, from the Committee on Energy and Natural Resources, submitted the following

REPORT

[To accompany S. 1294]

The Committee on Energy and Natural Resources, to which was referred the bill (S. 1294) to promote the development of technologies which will enable fuel cells to use alternative fuel sources, having considered the same, reports favorably thereon with amendments and recommends that the bill, as amended, do pass.

The amendments are as follows:

1. On page 1, line 5, strike "1987" and insert "1988" in lieu thereof.
2. On page 2, line 4, strike "provide" and insert "authorize" in lieu thereof.
3. On page 2, line 9, insert ", pursuant to the Federal Non-Nuclear Energy Research and Development Act of 1974," after the word "program".
4. On page 2, line 21, insert ", subject to appropriations," after the word "may".
5. On page 3, line 3, strike "1989" and insert "1991" in lieu thereof.
6. On page 3, line 7, strike "1988" and insert "1990" in lieu thereof.

PURPOSE OF MEASURE

The purpose of the bill, as reported by the Committee, is to promote the development of technologies which will enable fuel cells to use alternative fuel sources.

S313-35

SUMMARY OF MAJOR PROVISIONS

S. 1294 as reported by the Committee is intended to encourage research on technologies that will enable fuel cells to use alternative fuel sources such as methane from biomass, wind energy, and solar energy. The bill directs the Secretary of Energy to implement and carry out a research program and authorizes the Secretary of Energy to make grants to, or contract with private research laboratories, subject to appropriations, for that purpose. The Secretary is directed to transmit to Congress by September 30, 1991, a comprehensive report on the research carried out under this legislation. The bill also authorizes $5 million for fiscal year 1990 for conducting this research.

BACKGROUND AND NEED

The goal of Federal research in fuel cells since the mid-1970's has been to develop a highly energy efficient technology with especially desirable characteristics for electric power production. These char acteristics include high performance, fuel flexibility, low environmental impact, small size and spinning reserve capability. The primary national gains expected from this research are increased fuel use efficiency, substitution of alternate fuels for conventional fuels, and the potential for improving our national balance of trade through the export of fuel cell technology.

Federal investment in fuel cell technology research and development over the prior 10-year period was $260 million. This research and development program has been built largely upon Congressional initiatives. The point of commercial payoff for this large investment appears to be fast approaching, but a strategy and policy for acting upon the research findings has not yet been implemented. This bill is aimed at achieving such a policy change by encouraging the development of fuel cells integrated with renewable energy resources.

The fuel cell, an electro-chemical device first constructed by Sir William Grove in 1839, had its first practical application in the Gemini V flight of August 1965, where it proved to be an efficient, reliable power generator with very high-energy density. Fuel cells operate by combining hydrogen-rich gas with air and converting the chemical energy directly into electricity without any intermediate combustion step. This contributes to its high efficiency rate of 40–60 percent. In addition, the heat generated is sufficient to permit cogeneration space heating, for an overall efficiency rate as high as 80 percent. A typical cell produces high, direct current in a low voltage. Practical voltages are obtained by connecting many individual cells into what is referred to as a cell stack.

Besides their high efficiencies, fuel cells offer a number of other advantages, including economy and size. They can be factory assembled, leading to short construction lead times and put on line in relatively short periods of time. The capital outlay and interest costs for fuel cell technologies are expected to compare favorably with other power generation technologies. In addition, their modular design means that output can be increased incrementally, which allows for a closer match between capacity and anticipated demand growth. Hence this technology holds promise for both cen-

tralized and decentralized power systems, including hybrid applications with renewable systems.

LEGISLATIVE HISTORY

S. 1294 was introduced on May 28, 1987, by Senator Matsunaga for himself, and Senators Weicker, Inouye, Murkowski, and Bingaman. On September 23, 1987, the Subcommittee on Energy Research and Development held a legislative hearing on the bill.

The Subcommittee heard testimony on S. 1294 from a variety of witnesses representing electric utilities, fuel cell manufacturers and industrial users, university research programs, the Department of Energy, and industry organizations. A number of witnesses cited the contribution that fuel cell technology might be expected to make to improve the Nation's international trade balance due to its potential applications for decentralized, hybrid power systems in overseas markets.

COMMITTEE RECOMMENDATION AND TABULATION OF VOTES

The Committee met in open business to consider S. 1294 on July 27, 1988. The Committee, with a quorum present, recommended that the Senate pass S. 1294, if amended as described herein. The roll call vote on the reporting of the measure was unanimous

YEAS

Mr. Johnston
Mr. Bumpers
Mr. Ford
Mr. Metzenbaum*
Mr. Melcher
Mr. Bradley
Mr. Bingaman*
Mr. Wirth
Mr. Fowler
Mr. Conrad*
Mr. McClure
Mr. Hatfield*
Mr. Weicker*
Mr. Domenici*
Mr. Wallop
Mr. Murkowski
Mr. Nickles
Mr. Hecht*
Mr. Evans

*Indicates vote by proxy.

COMMITTEE AMENDMENT

The Committee amendments, generally technical in nature, accomplish the following things. First, they bring the bill up-to-date by authorizing funding for a research program on fuel cells using alternative fuel sources for fiscal year 1990, instead of fiscal year 1988, and by moving the report to Congress on that research up by two years to the end of fiscal year 1991. The amendments also

bring the title of the bill up-to-date by changing the "1987" in the title to "1988."

Other Committee amendments make it clear that all research carried out pursuant to this bill is consistent with the Federal Non-Nuclear Research and Development Act of 1974, the umbrella authorization legislation for research of this nature. The amendment also states that the purpose of this bill is to authorize funds, not provide them, and that the grant and contract authority of the Secretary is limited by appropriations.

SECTION-BY-SECTION ANALYSIS

Section 3 directs the Secretary of Energy to implement and carry out a research program on technologies that will enable fuel cells to use alternative fuel sources, and authorizes the Secretary of Energy to make grants to, or contract, subject to appropriations, with private research laboratories for that purpose.

Section 4 directs the Secretary of Energy to transmit to Congress by September 30, 1991, a comprehensive report on the research carried out under this legislation.

Section 5 authorizes $5 million in Fiscal Year 1988 for conducting this research on technologies which enable fuel cells to use alternative fuel sources.

COST AND BUDGETARY CONSIDERATIONS

The following estimate of costs of this measure has been provided by the Congressional Budget Office:

REGULATORY IMPACT EVALUATION

U.S. CONGRESS,
CONGRESSIONAL BUDGET OFFICE,
Washington, DC, July 29, 1988.

Hon. J. BENNETT JOHNSTON, Jr.,
Chairman, Committee on Energy and Natural Resources,
U.S. Senate, Washington, DC.

DEAR MR. CHAIRMAN: The Congressional Budget Office has reviewed S. 1294, the Renewable Energy/Fuel Cell Systems Integration Act of 1988, as ordered reported by the Committee on Energy and Natural Resources, July 27, 1988. CBO estimates that enacting S. 1294 would increase federal outlays by $3 million in fiscal year 1990 and $2 million in fiscal year 1991, assuming appropriation of the authorized amount.

S. 1294 would create a research within the Department of Energy to develop fuel cell technologies that use alternative fuel sources such as biomass, wind, and solar energy. The proposed program would also explore possibilities for using fuel cells in conjunction with renewable power systems in rural and isolated areas. The bill authorizes the appropriation of $5 million in fiscal year 1990 for conducting the renewable energy/fuel cells research.

The bill would not have any effect on the budgets of state and local governments.

If you wish additional details on this estimate, we will be pleased to provide them. The CBO staff contact is Peter Fontaine, who can be reached at 226–2860.

Sincerely,

JAMES L. BLUM, *Acting Director.*

The bill is not a regulatory measure in the sense of imposing Government-established standards or significant economic responsibilities on private individuals and businesses. S. 1294 as reported authorizes a research program to promote the development of fuel cells using renewable energy resources, authorizes the Secretary of Energy to make grants to or contract with private laboratories for the purpose of carrying out this research, directs the Secretary of Energy to submit a report on the research carried out pursuant to this Act.

No personal information would be collected in administering this program. Therefore, there would be no impact on personal privacy from S. 1294.

EXECUTIVE COMMUNICATIONS

There were no legislative reports or communications received by the Committee from the Administration relating to S. 1294.

The Administration testified on the legislation at a hearing before the Subcommittee on Energy, Research and Development on September 23, 1987. The written testimony of Assistant Secretary Donna Fitzpatrick is reprinted below.

Statement of

Donna R. Fitzpatrick
Assistant Secretary
for
Conservation and Renewable Energy

U.S. Department of Energy

to the

Senate Committee on Energy and Natural Resources
Subcommittee on Energy Research and Development

September 23, 1987

.. Chairman and Members of the Committee:

Thank you for the opportunity to appear before you today to discuss the Department of Energy's hydrogen and advanced fuel cell programs, and the Senate bills S. 1294 and S. 1296 relating to hydrogen and fuel cells.

OVERVIEW ON HYDROGEN

Hydrogen is an abundant element but it does not occur in Nature in the pure state. It has been known to man for about two centuries. It was initially used as a buoyant gas, then as a synthetic-fuel constituent. At present, hydrogen is used almost entirely as a unique industrial chemical in petroleum processing and in synthesis of ammonia and methanol.

In addition to the dominating applications in petroleum refining, ammonia synthesis for fertilizer production, and methanol manufacturing, hydrogen as a chemical has a range of miscellaneous and special uses. Hydrogen is used in the production of foodstuffs, including margarines and cooking fats, and in the manufacture of soap. It serves in the refining of certain metals, in semiconductor manufacture, and for the annealing of metals. It is employed in uranium extraction and processing and for corrosion control in nuclear reactors. Hydrogen also cools electrical generators in utility power stations and is a feedstock in organic

chemical synthesis leading to production of nylon and polyurethane. It is a high energy rocket fuel and an experimental aviation and automotive fuel. The use of hydrogen in each of these applications is quite specialized, but they illustrate the range of industrial uses that already exist.

Hydrogen is not, however, a primary energy source--it must be manufactured. Practically all the hydrogen now produced in this country is manufactured from natural gas and light oils. It must be recognized that as a secondary energy form, the energy to be derived from hydrogen will always be less than the energy required to produce it.

Since hydrogen does not exist on earth in its elemental form, to obtain hydrogen requires conversion of compounds containing hydrogen. This conversion requires energy sources such as coal, solar, or nuclear to be consumed to be able to produce hydrogen. This energy consumption is substantial, currently requiring from 4 to 15 units of raw energy to manufacture 1 unit of hydrogen energy, depending on whether the product is gaseous, liquid, or "slush". Therefore, hydrogen technology represents only a potential bridge between energy sources such as solar, nuclear, and coal and energy consumers such as the various applications mentioned earlier. This is similar to the existing electric power grid or the battery

technologies under development. To determine whether widespread use of hydrogen should take place, the complexities, energy cost, and dollar cost associated with changing our energy production and distribution network must be addressed.

From an energy perspective, the question is not whether the Nation can use hydrogen for many applications now served by electricity or other energy carriers, but should we use it in this way. It is technically possible to connect almost any source to any energy use by means of hydrogen. Our judgment on whether to use this bridge should be governed by the total cost to society. When it becomes more convenient and more economical, it will be used.

RATIONALE FOR HYDROGEN RESEARCH

Today hydrogen can be produced via a number of processes, but it must be remembered that the resulting hydrogen comes from the consumption of other fuel sources and, therefore, cannot be as energy efficient as using the primary fuel. Therefore, if hydrogen is to be used in a greater variety of applications, improvements will be required in several areas to improve the efficiency of hydrogen production. Also, more effective storage systems for both bulk and mobile will be required.

For the production of hydrogen, water electrolysis is the most mature of the water-splitting technologies in use by industry. In DOE sponsored work, advances have been made in electrocatalysis, electrode materials, separators, and electrolytes. Research is still needed to reduce capital cost and maximize reliability for large-scale systems. New developments in water vapor electrolysis conducted at temperatures up to 100 C promise overall efficiency improvements of 30%-50% over lower temperature water electrolysis technology. Other techniques of water splitting, such as photochemical or biological processes, are infant technologies that show promise for the long term.

Hydrogen can also be produced from coal, natural gas, or renewable sources (wind, ocean). Production from natural gas is the least expensive; costs for other sources can be three to 30 times higher, largely because of the energy consumed by the production process. Therefore, an inexpensive renewable energy source could be the key to the economically competitive production of hydrogen. This suggests that continued research to improve the technology base of renewable energy conversion systems is itself an important step in promoting increased hydrogen use.

Hydrogen storage continues to be a problem. It has been suggested that long-term bulk storage of hydrogen can take place in depleted oil wells and caverns but extensive testing has not been conducted. For mobile applications, metal hydrides -- where hydrogen is temporarily chemically bound to a porous metal matrix -- have been investigated but this form of storage today is an expensive alternative to compressed gas and liquefied hydrogen.

Hydrogen embrittlement of conventional pipeline steels is recognized as a primary deterrent to hydrogen transport at high pressures. Fundamental investigations have verified the embrittlement phenomena and studies have been extended toward identification of embrittlement suppression techniques. Recent investigations have shown that introduction of oxidants as low-concentration additives to hydrogen streams may offer means for suppressing embrittlement.

S. 1296

Let me turn first to specific comments on the Senate bill on hydrogen, specifically Title I of S. 1296, pertaining to the Department of Energy.

The intentions of the bill are good. To prepare for the future is both wise and prudent. This is also the goal of the Department in carrying out its research into ways to produce and

store hydrogen, along with other energy technologies that may serve the same purpose.

As stated, considerable progress has been made in understanding just what is needed to have hydrogen as an alternative energy carrier in the future. Our research is continuing to find improvements in producing, storing, and transporting hydrogen for transportation, process heating, fuel cells, and other applications.

The DOE plans to continue its research and development in hydrogen and believes that the spirit of the proposed legislation can be carried out through its existing program. New legislation is, therefore, not required to accomplish the intent of S. 1296, Particularly in a time of tight budgets, we believe taxpayer dollars are best spent on longer range, more generic research that benefits all areas of hydrogen production, storage, and transportation. Until these fundamental issues are resolved, demonstration and commercialization activities (which are more appropriately the province of the private sector) will not efficiently provide significant progress toward achievement of the objective of S. 1296. Clearly, the Government can provide the most effective contribution by establishing a technology base on which industry can build. Our current hydrogen research has been carefully fashioned to ensure that tax dollars are not supplanting

private sector funding. We will continue to make available to the private sector the results of our technology base research and we will encourage them to exploit this knowledge. The Department of Energy is continuing to expand the range of technical options available to the private sector, including the use of hydrogen, that will improve our Nation's energy future. For these reasons, we do not support this legislation.

I have included in my testimony two attachments, one which further describes the Department of Energy's hydrogen-related research in the Office of Basic Energy Sciences and a second one which elaborates on the Chemical/Hydrogen Energy Storage project in the Office of Energy Storage and Distribution.

Let me turn now to the area of advanced fuel cells, and Senate bill S. 1294 which relates to fuel cells.

OVERVIEW OF ADVANCED FUEL CELLS

The DOE fuel cell program can trace its origins to work that began more than two decades ago in laboratory and special applications research. Today this effort has evolved into a multi-faceted research program. The Office of Conservation and Renewable Energy currently oversees research on Phosphoric Acid fuel cells for transportation applications and manages research on Solid Polymer Electrolyte fuel cells - also known as Proton

Exchange Membrane (PEM) fuel cells. The future application for the latter technology will be predominantly for mobile, and remote.

This multi-pronged effort is internally coordinated, with all elements of the Department exchanging results and future plans on a regular basis.

Technology Descriptions

Fuel cells are energy conversion devices that convert chemical energy directly into electric energy without the inherent efficiency limits of heat engine cycles. A complete fuel cell power plant would typically include a fuel processing section (such as a reformer or a coal gasifier section with gas cleanup), a power producing section (often referred to as the fuel cell stack), and a power processing section with a direct-current-to-alternating current invertor.

Fuel cells are powered by the electrochemical combination of hydrogen and oxygen. The source of hydrogen can vary considerably; virtually any hydrocarbon fuel can be a potential feedstock for a fuel cell power plant, although for economic reasons, coal, natural gas, other sources of methane and methanol will likely be the principal fuels.

Higher operating temperatures may provide significant efficiency and capital cost advantages; however, elevated temperatures are not suitable for all potential fuel cell applications. In particular, the choice of a fuel cell for some mobile applications may be dictated, in large part, by the need for a system capable of operating at reduced temperatures, i.e., the phosphoric acid or proton-exchange membrane technology. Other concepts in the very early development phases (such as the monolithic solid-oxide concept) may offer low-weight and low-volume systems compatible with some mobile applications.

Applications and Research Emphasis

Programs are in progress at Brookhaven National Laboratory and at Los Alamos National Laboratory (LANL) for the investigation of fuel cells for vehicular propulsion. Some of the above advantages of fuel cell power plants over thermal ones for electric and gas utility power generation apply equally well for vehicular power plants. The significant one is that the projected efficiencies for fuel cells are at least twice as high as those for internal combustion and diesel engines.

Transportation's share of petroleum use in the United States reached 64% in 1986. This figure represents 108% of domestic production and indicates the impact that changes in the transportation area can have on petroleum needs. The objective of the fuel cell work at LANL is to help reduce U.S. dependency on petroleum resources and to provide full performance vehicles. Fuel cells possess a number of attributes that make them very attractive for transportation applications. Their high efficiency and ability to use non-petroleum fuels address the petroleum dependency problem. Their operational simplicity, safety, and low pollution are features that make them desirable for use in cars and trucks. The fuel cell system chosen for a given application must be selected on the basis of performance and of type of fuel required. Based on the state-of-development, fuel considerations, and the inherent restrictions imposed by vehicular applications, only acid fuel cells, phosphoric acid (PA) and proton exchange membrane (PEM), operating on reformed methanol and air are being considered at the present time. The PA fuel cell is the choice for near-term use, because it represents the only technology that has demonstrated full-stack operation on reformed fuel. The potential of the PEM fuel cell in terms of high power density, low-temperature operation, rigid and contained electrolyte, and cold start capability dictated its consideration, even though the system technology development is immature for terrestrial operation on reformed fuel.

In summary, simulation studies indicate that it is feasible to use fuel cell or fuel cell/battery hybrids in city buses and in passenger cars. Improvements in technology should enhance this feasibility of using fuel cells in transportation. Fuel cell use in the transportation sector will depend upon the success of ongoing research efforts to overcome constraints on cost, size, and operating conditions.

Another area of fuel cell application, sponsored by the American Gas Association, is the residential and commercial buildings sector. Strong interest by the gas utilities is evidenced by the recently completed field test of nearly fifty 40-kilowatt power plants producing electricity and cogenerated heat. Introduction of commercial gas-using fuel cells in this sector is expected in the 1990s. Due to the smaller size required of fuel cell power plants for the residential sector, (several kW), and also because of competitive economic constraints, fuel cells are unlikely to find application in the residential sector in the immediate future. Use of feedstocks such as coal or biomass in these applications will likely depend upon the economic competitiveness of processes to convert these fuels into pumpable gaseous or liquid products and the existence of suitable delivery systems.

Fuel cell use in the industrial sector could follow introduction in the electric utility sector and basically rely on modules similar to those being developed for electric utility plants.

Renewable Fuel Cell Program

Solid Polymer Electrolyte Fuel Cell Systems: This system is being considered for transportation applications. Because the system operates at less than 100 C, methanol is the most appropriate liquid fuel to be reformed and used in this fuel cell system. Progress had been made at Los Alamos National Laboratory to reduce the noble metal, e.g., platinum, loading to one-tenth that of the previous state-of-the-art system. This is done by incorporating a proton conductor into the electrode structure to extend the three-dimensional reactor zone. Water management can be achieved by optimum humidification of the system. Prospects are good for attaining high power densities (those over 500 mW/cm^2).

Direct Methanol Fuel Cell: A fuel cell researcher's dream is to oxidize organic fuels (preferably methanol, which can be produced from biomass or coal) rather than to process these to hydrogen, which is, in turn, oxidized in the electrochemical cell. Methanol is the most active electro-organic fuel, but its activity is 3 orders-of-magnitude less than that of hydrogen. Thus, under these conditions, current-densities of about 50 mA/cm^2 are obtained at cell potentials of 0.4 V, somewhat lower than desired. Even at these current densities, there is a performance degradation with time. The main cause for the degradation is that the intermediates formed during methanol oxidation poison the platinum electrocatalyst. The poisoning effects are less with some alloy electrocatalysts (e.g., Pt-Ru, Pt-Sn) and with platinum electrocatalysts with additional atoms such as Bi, Pb, Sn, Ge.

Prognosis of Economics and Applications of Fuel Cell Systems

The applications of fuel cell systems have been well-demonstrated in space venicles. Capital costs are not such an overriding factor for space applications as they are for terrestrial applications. The alkaline, and possibly the solid polymer electrolyte fuel cell, systems will continue to be the auxiliary power sources for space vehicles. The present price of crude oil makes it more difficult to introduce fuel cell systems

into the terrestrial arena. On the other hand, environmental constraints can also accelerate the entry of fuel cell technologies.

The bottom line with respect to economics of fuel cells for terrestrial applications will be the cost of electricity generated, which, in turn, will depend on capital costs, efficiency, and life-time. Taking into consideration the performances of fuel cells for terrestrial applications, the major factors to be overcome are: (1) development of automated techniques to reduce the capital costs of the system; (2) achievement of reliability of performance over the required lifetimes; (3) demonstration of economic, technical, and environmental advantages of dispersed, on-site integrated energy and cogeneration power plants; and (4) development of a niche for electric vehicles - in plants, military uses, buses, trucks, and automobiles.

The factors that impede the commercialization of fuel cells are that improvements are needed in the areas of initial cost, lifetime and performance. More specific barriers are the high cost of electrocatalysts and porous electrodes; the corrosion of active and passive cell components; instabilities of porous electrode

structure under long-term cycling; loss of electrocatalytic activity with time and use; inadequate conductivity of electrolytes for high-performance (power) application and lack of advanced electrodes and cell-designs for high-performance applications. By addressing these issues the DOE programs will improve the base technology to the point where industry can develop commercial prototypes.

S. 1294

The purpose of the bill, stated as "exploring the operation of fuel cells employing methane gas generated from various forms of biomass", will be a good match with the type of fuel cell and fuel processor being developed. The focus is on solid polymer electrolyte fuel cells, because they offer the potential for higher power density fuel cells; they tolerate carbon dioxide in the fuel streams, and therefore can use reformed methane, methanol, or

hydrogen; and they operate below one-hundred degrees centigrade, allowing low temperature startup and use of low-cost structural material. The operation of cells on reformed methanol and hydrogen is currently being investigated and the prototype fuel cells will also be tested with reformed methane.

As I have explained, production of hydrogen by water electrolysis and photoelectrochemical methods are part of the hydrogen program. Hydrogen is currently used as a fuel cell fuel. Currently there are no activities related to the third purpose of the bill, "determining the technical requirements for employing fuel cells for power production as backup spinning reserve components to renewable power systems in rural and isolated areas." This is an area that should be carried out in the future but currently has a low priority because of the immaturity of the technology.

Where government can provide the most effective contribution to fuel cell technology is in building a solid base of technological information which industry can use to make market-oriented, developmental decisions.

Our current fuel cell program, particularly as it is presented within the President's Fiscal Year 1988 budget request, has been carefully fashioned to ensure that tax dollars are not supplanting private sector funding. We will continue to make available to the private sector the results of our technology base research and will encourage them to implement this research when market forces dictate.

The Department of Energy is committed to expanding the range of technical options available to the private sector that will improve our Nation's energy future; fuel cells are a sound prospect for this future. Current programs are adequately funded to address the intent of these bills. Any future activities will be considered as part of the budget process. For this reason, we do not think this legislation is necessary. As I indicted previously, the remaining pages of our testimony provide more details on the ongoing fuel cell efforts with the Department of Energy.

Thank you for the opportunity to discuss this area of research with you today.

ATTACHMENT 1

HYDROGEN-RELATED RESEARCH

The Office of Basic Energy Sciences (BES) supports long-range basic energy-related research and is charged with providing the fundamental scientific foundation for the Nation's future energy options. Accordingly, some of the 1400 individual research projects in the areas of physical and biological sciences, engineering, and geosciences are related to DOE's interests in hydrogen. The hydrogen-related research supported by BES is found largely in the divisions of Chemical Sciences, Materials Sciences, and Energy Biosciences. In almost all cases, the research is long range and generic with very little research being focused directly on a specific energy technology.

The Chemical Sciences research includes basic solar photochemistry, biomass chemistry related to dissociation of water, and hydride research for the storage of hydrogen. The focus of the Chemical Sciences programs as it relates to hydrogen is on the fundamental understanding of the chemistry involved in production and storage concepts at the most basic level.

In our fundamental research program in solar photochemistry energy conversion, fundamental processes are being explored which can be applied to hydrogen production by splitting the water molecule into its components, hydrogen and oxygen, to methanol production from carbon dioxide, ammonia synthesis from atmospheric nitrogen, or to production of other needed chemicals at lower energy cost by using sunlight. The research is expected to provide the basis for new solar chemical technologies in the distant future.

Solar photochemistry research is proceeding on several fronts. In plant and bacterial photosynthesis research, the emphasis is on understanding how sunlight initiates the primary steps of photosynthesis at the molecular level. This insight is being used to design simple molecules which can absorb light and use its energy to separate charges long enough to drive useful chemical reactions. Other research involves photocatalytic chemical reactions in homogeneous and heteorogeneous systems. Particularly noteworthy in this area are metal catalyst-coated semiconductor colloidal particles in solution, where product separation may be achieved by vesicles or bilayer membranes. Other reaction systems involve photosensitization by porphyrins or other visible light-absorbing chromophores. The key to success in the design of these systems is more efficient electron transfer in the forward direction than the reverse, which necessitates careful mechanistic and kinetic experiments. Photoelectrochemistry is perhaps the most

advanced area of solar photochemistry research, although no known semiconductor is the perfect candidate. Semiconductor electrodes which absorb in the visible region must be protected from photocorrosion in aqueous solution, which is being achieved by coatings of transparent conducting polymers. Other semiconductors which are photostable in water but absorb outside the visible region are being modified with pendant chromophores photocatalysts to drive the chemical reactions of interest.

Other efforts in chemical sciences include the study of photosynthetic evolution of hydrogen from biomass systems using enzyme catalytic processes and the chemical aspects of hydrogen storage in hydride systems. The latter includes the determination of thermochemical properties and structural parameters to understand their behavior on hydriding characteristics.

The Materials Sciences programs related to hydrogen are focused on obtaining a fundamental understanding of the interactions of hydrogen with materials. These programs are, therefore, necessarily basic or generic in character and do not directly engage in the development of specific technologies for a hydrogen economy. They do, however, provide fundamental understanding necessary for the development of these and other related technologies; for example, technologies related to hydrogen storage, end-use, and synfuel production. Specifically, research is underway on diffusion of hydrogen in rare earth, on refractory

metal alloys, on the uptake and the thermodynamics and kinetics of hydrogen in noble metals, on behavior of hydrogen on metal surfaces, on a theoretical understanding of the effects of hydrogen on bonding in metals, on hydrogen attack, on a phenomenon that occurs in some steels subjected to high-temperature, high-pressure hydrogen as a coal gasification process, and on protonic conduction in solid electrolytes as might be encountered in batteries or fuel cells.

The Division of Energy Biosciences supports research aimed at understanding the mechanisms involved in the biological production and utilization of molecular hydrogen. The long-term objective of the program is to provide the requisite scientific foundation for the development of novel biotechnologies based on hydrogen as an energy resource or ones in which hydrogen plays an integral role in the production of other products such as methane. The emphasis of the research supported is on the bioenergetics of hydrogen production and the enzymes, the hydrogenases, responsible for the production of hydrogen driven by light energy directly or indirectly through renewable plant resources. The related hydrogenases responsible for the transfer of hydrogen between species of anaerobic bacteria is also a research area supported. Effort also focuses on understanding the group of enzymes which are responsible for hydrogen production, hydrogen transfer, or hydrogen

utilization. Their molecular structure, genetic and metabolic regulation mechanism of action, oxygen liability, and involvement of metals are all subjects of investigation.

ATTACHMENT 2

CHEMICAL/HYDROGEN ENERGY STORAGE PROGRAM

Background

For the past decade, DOE has pursued mission-oriented hydrogen technology development. These programs concentrate on long-term technology-base developments geared to conversion, storage, and transport.

PROGRAM RATIONALE AND STRATEGY

Chemical/hydrogen energy systems (C/HES) are identified as a candidate link between renewable primary resources and energy demand sectors. Current economics and the availability of conventional energy resources place the exercise of the C/HES option well into the far term. Therefore, a long-range program has been structured to develop a technology base across the full spectrum of conversion/production, storage, and transport technologies. The R&D investment is viewed as increasing the flexibility to accommodate a different mix of energy supply sources in the future.

Cost Performance Objectives

The versatility of hydrogen as a fuel and chemical commodity and its environmentally benign characteristics have been well documented. It remains for a technology base to be developed which

will effectively establish cost effective benefits. Conversion of various resources to a secondary chemical energy form, such as hydrogen, calls for achieving high conversion efficiencies at minimal capital outlay. Effective storage of this chemical energy in bulk and mobile systems is required to offset energy supply-demand mismatches and to provide on-board energy storage options for vehicular transport.

The conversion, storage, and transport requirements have been translated to specific cost and performance objectives for each element of the program.

- o Hydrogen Production Cost -- $10/MMBtu (1980 dollars)
- o Storage Cost ---------- $1-3/MMBtu (1980 dollars)
- o Storage Density ---------- Greater than 4% by weight for metal hydrides or 2500 BTU's per lb.
- o Transport ---------- Long-Term Stability (conventional pipeline)

Technology State-of-the-Art

Hydrogen Production - Historically, this segment of the program has been concerned with developing alternatives to steam reforming of natural gas for the production of hydrogen, with emphasis placed

mainly on the dissociation of water via electrolysis. Energy used for dissociating water can be in the form of heat or electricity. Since Carnot limitations of steam cycles used to produce electricity imply an efficiency ceiling, it would appear prudent to pursue the direct utilization of heat in water-splitting processes. Thermal decomposition processes operating in the extreme temperature regimes (greater than 3000 C) do not bode well with regard to materials availability and process simplicity. Substantial efforts in the past have been directed toward identifying thermochemical cycles which could alleviate some of the process engineering difficulties; however, materials handling, corrosion, and process complexity remain major problems.

Technical judgments suggest that a combination of thermal and electrochemical processes can be optimized via development of high-temperature (300C-1000C) water vapor dissociation. Such systems can result in overall energy efficiencies approaching 50%.

Determining the cost of producing this hydrogen is not a simple matter. This cost depends upon the cost of electricity (peak or offpeak), capital cost, and utilization factor. As a rule of thumb, hydrogen can be produced from natural gas for about $6-9/MMBtu. Electrolytic hydrogen can be produced for about $15-25/MMBtu. Due to the uncertainties in electricity cost, utilization factor, and capital costs, it is difficult to project future markets for hydrogen.

Hydrogen Storage - Current practice relies on compressed gas or liquefied hydrogen as the primary storage options. These storage systems do not lend themselves to bulk long-term or mobile short-term storage applications necessary if hydrogen is to assume an expanded role in the future U.S. energy infrastructure.

Substantial efforts in the U.S. and abroad toward advancing hydrogen storage technology have been only moderately successful. Various metal hydrides based typically on iron-titanium and magnesium alloys have been characterized and found wanting with regard to cost, weight/volume storage density, or required operating temperature/pressure regimes. Cryoadsorption of hydrogen in carbon at liquid nitrogen temperatures has been explored to some extent in Europe. DOE has supported R&D in advanced hydrides and in microcavities as hydrogen storage media.

Hydrogen Transport - Supplementation of natural gas with hydrogen is one option under consideration for future energy systems. Assuming efficient conversion of a given primary resource to hydrogen, some savings over electric energy transmission potentially could be realized if this energy were transported by pipeline. These are: reduced transmission losses limited to pressure drop and leakage compared to impedance losses, reduced capital cost of pipe compared to power transmission lines, reduced costs of right-of-way. To use this option, it is necessary to establish the compatibility of hydrogen with conventional pipeline

steels. Protective measures for ensuring the safe and effective transport of hydrogen via available pipelines would require research.

HYDROGEN ACCOMPLISHMENTS AND FUTURE NEEDS

Accomplishments over the past decade derived from the hydrogen component of the C/HES program are summarized:

- Solid Polymer Electrolyte (SPE) Water Electrolysis System--General Electric - Comprehensive R&D program culminated in the fabrication and test of a 200-kW system which approached high efficiency and cost goals. Another smaller 20-kW unit demonstrated reliable on-site production of hydrogen which was used for utility electric generator cooling. Technology subsequently sold to Hamilton-Standard which is currently pursuing commercial prospects.

- Static Feed Water Electrolysis--Life Systems, Inc. - Multicell (1 ft) module designed, fabricated, and tested, demonstrates the ability to electrolyze brackish water and sea water. The system eliminates need for electrolyte circulating pump as well as water treatment subsystem, thus maximizing reliability and permitting low-cost manufacturing of molded parts. Technology was

transferred to NASA-supported programs in Orbital Space Station Storage systems.

- Advanced Alkaline Water Electrolysis--Teledyne Energy Systems - Modest R&D program was able to demonstrate substantial improvements in electrolyzer elements (electrodes, catalysts, structural components). Limited success in separator development which would have permitted higher temperature (125-150C) operation.

- Underground Storage--IGT - Comprehensive engineering analyses show feasibility and problems of long-term storage in depleted wells and in caverns.

- Metal Hydride Storage - A wide range of alloys prepared and tested to show a safe alternative to compressed gas and liquefied hydrogen storage. Studies have shown, however, that low-cost, high-storage-density materials require high temperature for hydrogen release. On the other hand, low-temperature materials exhibit low storage densities and high cost.

- Rapid Cycling Applications (Metal Hydrides) - Chemical compressors in early states of commercialization. Metal hydride pair chemical heat pump proved viable for heating and cooling. Hydrogen separation/purification

shown to be an alternative to pressure-swing adsorption and cryogenic separation.

- Hydrogen Transport/Transmission - Long-term program initiated by Sandia and completed by Battelle Laboratories fully characterized key problems of hydrogen embrittlement in pipeline steels. Battelle also demonstrated that additive gases (inhibitors) eliminate a number of the embrittlement problems.

- Hydrogen Technology Evaluation Center (HTEC) - Brookhaven National Laboratory facility was used to demonstrate the characteristics of interfacing an advanced technology electrolyzer with a photovoltaic system for hydrogen production, with coupling to electric grid. The facility was also used to conduct a performance mapping of a metal hydride compressor operating in both the closed and open loop modes. Test programs provided an opportunity for training/technology transfer involving representatives from MIT, Florida Solar Energy Center, EPRI, Public Service Electric and Gas Company of New Jersey, and the University of Hawaii.

Ongoing R&D activities are briefly described:

- A study examining the potential of hydrogen derived from renewable energy sources is continuing. In this effort, the status of current renewable hydrogen technology will be compared with conventional hydrogen production and areas where additional research might result in significant improvements will be identified. The ability of an energy infrastructure to assimilate greater hydrogen usage will be addressed, using Hawaii as the model. A major hydrogen application derives from benefits in increasing the hydrogen/carbon ratio of biomass to produce liquid fuels, e.g., methanol.

- A major program is being conducted by Westinghouse developing their thin film solid oxide technology for high-temperature water vapor electrolysis applications. Cell testing has shown performance in the 1.3 V range at current densities of 300 A/ft^2, and also conversion of up to 90% of steam to hydrogen and oxygen. A comprehensive theoretical model of vapor electrolysis is being developed which will provide information to improve performance.

- Several activities are underway investigating medium-temperature electrolysis in the 300-600 C temperature range. Brookhaven National Laboratory and Politecnico di Milano have recently completed characterization of aluminum phosphate and barium sulfate as "unsuccessful" candidate materials. In a parallel investigation the University of Pennsylvania has examined the use of beta alumina as a proton-conducting material suitable for medium-temperature electrolysis. Data have been obtained on thermal stability and conductivity as a function of water vapor pressure. Subsequent to a competitive procurement, Stanford University has identified a novel hydrogen ion conducting electrolyte which may provide a basis for a successful intermediate temperature range water vapor electrolysis system. Further, this electrolyte may serve to enhance prospects for using low cost hydrides as hydrogen storage media via the electrochemically - assisted dehydriding reaction.

- Battelle Columbus is addressing a novel approach to photolytic hydrogen production making use of plasma/polymer-coated semiconductor electrodes. Progress has been made in optimizing stability, optical transparency, and electrochemical cell characteristics.

- A key program in hydrogen storage is going on at Syracuse University attempting to make use of catalyzed, activated carbon to store hydrogen at low temperatures suitable for use in mobile/stationary applications. Adequate storage has been demonstrated on the macro scale but only at very low liquid nitrogen temperatures. Current work is investigating higher pressure, higher temperature operation, and alternate carbon materials. A class of super-activated carbons treated to provide high surface acidity has been found to satisfy 4% by weight system requirements at temperatures of 150 K (liquid freon temperatures).

CHANGES IN EXISTING LAW

In compliance with paragraph 12 of rule XXVI of the standing rules of the Senate, the committee notes that no changes in existing law are made by the bill S. 1294 as reported.

○

19-010 O (39)

Calendar No. 874

100TH CONGRESS
2d Session

SENATE

REPORT
100-458

FUEL CELLS ENERGY UTILIZATION ACT OF 1988

AUGUST 5, 1988.—Ordered to be printed

Mr. JOHNSTON, from the Committee on Energy and Natural Resources, submitted the following

REPORT

[To accompany S. 1295]

The Committee on Energy and Natural Resources, to which was referred the bill (S. 1295) to develop a national policy for the utilization of fuel cell technology, having considered the same, reports favorably thereon with an amendment and recommends that the bill, as amended, do pass.

The amendment is as follows:

On page 1, line 5, strike "1987" and insert "1988" in lieu thereof.

PURPOSE OF MEASURE

The purpose of the bill, as reported by the Committee, is to develop a national policy for the utilization of fuel cell technology.

SUMMARY OF MAJOR PROVISIONS

S. 1295 as reported by the Committee on Energy and Natural Resources contains the following three major provisions:

(1) Section 256 of the Energy Policy and Conservation Act (EPCA) is amended to include industries using fuel cell technologies under the term "domestic renewable energy industry". Section 256 of EPCA requires the Secretary of Commerce and the Secretary of Energy to conduct certain activities aimed at enhancing commerce in the domestic renewable energy industry.

(2) The Administrator of the Environmental Protection Agency is directed to prepare Federal guidelines for cities and municipalities specifying environmental and safety standards for the use of fuel cell technologies.

19-010

S.Rept. 100-458 O - 88 - 1

S 313-36

(3) The Secretary of Commerce is directed to assess and report to Congress within 180 days of enactment regarding the export potential for integrated systems of fuel cells with renewable power technologies.

Background and Need

The fuel cell, an electro-chemical device first constructed by Sir William Grove in 1839, had its first practical application in the Gemini V flight of August 1965, where it proved to be an efficient, reliable power generator with very high-energy density. Fuel cells operate by combining hydrogen-rich gas with air and converting the chemical energy directly into electricity without any intermediate combustion step. This contributes to its high efficiency rate of 40–60 percent. In addition, the heat generated is sufficient to permit cogeneration space heating, for an overall efficiency rate as high as 80 percent. A typical cell produces high, direct current in a low voltage. Practical voltages are obtained by connecting many individual cells into what is referred to as a cell stack.

Besides their high efficiencies, fuel cells offer a number of other advantages, including economy and size. They can be factory assembled, leading to short construction lead times and put on line in relatively short periods of time. The capital outlay and interest costs for fuel cell technologies are expected to compare favorably with other power generation technologies. In addition, their modular design means that output can be increased incrementally, which allows for a closer match between capacity and anticipated demand growth. Hence this technology holds promise for both centralized and decentralized power systems, including hybrid applications with renewable systems.

The goal of Federal research in fuel cells since the mid-1970's has been to develop a highly energy efficient technology with especially desirable characteristics for electric power production. These characteristics include high performance, fuel flexibility, low environmental impact, small size and spinning reserve capability. The primary national gains expected from this research are increased fuel use efficiency, substitution of alternate fuels for conventional fuels, and the potential for improving our national balance of trade through the export of fuel cell technolgy.

Federal investment in fuel cell technology research and development over the prior 10-year period was $260 million. This research and development program has been built largely upon Congressional initiatives. The point of commercial payoff for this large investment appears to be fast approaching, but a strategy and policy for acting upon the research findings has not yet been implemented. This bill is aimed at achieving such a policy change. It is intended that by requiring Federal agencies to specificially recognize this technology through existing information channels, the Congress will be expediting the acceptance of fuel cells into the commercial market worldwide.

Legislative History

S. 1295 was introduced on May 28, 1987, by Senator Matsunaga for himself, and Senators Weicker, Inouye, Murkowski, and Binga-

man. Senator Hecht was added as a cosponsor of the bill on November 18, 1987. On September 23, 1987, the Subcommittee on Energy Research and Development held a legislative hearing on the bill.

The Subcommittee heard testimony on S. 1295 from a variety of witnesses representing electric utilities, fuel cell manufacturers and industrial users, university research programs, the Department of Energy, and industry organizations. A number of witnesses cited the contribution that fuel cell technology might be expected to make to improve the Nation's international trade balance due to its potential applications for decentralized, hybrid power systems in overseas markets.

Committee Recommendation and Tabulation of Votes

The Committee met in open business to consider S. 1295 on July 27, 1988. The Committee, with a quorum present, recommended that the Senate pass S. 1295, if amended as described herein. The roll call vote on the reporting of the measure was unanimous:

YEAS

Mr. Johnston
Mr. Bumpers
Mr. Ford
Mr. Metzenbaum [1]
Mr. Melcher
Mr. Bradley
Mr. Bingaman [1]
Mr. Wirth
Mr. Fowler
Mr. Conrad [1]
Mr. McClure
Mr. Hatfield [1]
Mr. Weicker [1]
Mr. Domenici [1]
Mr. Wallop
Mr. Murkowski
Mr. Nickles
Mr. Hecht [1]
Mr. Evans

[1] Indicates vote by proxy.

Section-by-Section Analysis

Section 2 is self-explanatory.

Section 3 amended section 256 of the Energy Policy and Conservation Act (EPCA) to include fuel cell technology as a "domestic renewable energy industry" for the purposes of that Act. Section 256 of EPCA requires the Secretary of Commerce and the Secretary of Energy to coordinate activities aimed at enhancing commerce in renewable energy technologies.

Section 4 directs the Administrator of the Environmental Protection Agency (EPA) to prepare Federal guidelines for cities and municipalities specifying environmental and safety standards for the use of fuel cell technologies.

Section 5 requires the Secretary of Commerce to assess and report to Congress concerning the export market potential for fuel cells integrated with renewable energy technologies.

Cost and Budgetary Considerations

The following estimate of costs of this measure has been provided by the Congressional Budget Office.

U.S. Congress,
Congressional Budget Office,
Washington, DC, July 29, 1988.

Hon. J. Bennett Johnston, Jr.,
Chairman, Committee on Energy and Natural Resources, U.S. Senate, Washington, DC.

Dear Mr. Chairman: The Congressional Budget Office has reviewed S. 1295, the Fuel Cells Energy Utilization Act of 1988, as ordered reported by the Senate Committee on Energy and Natural Resources, July 27, 1988. CBO estimates that enacting S. 1295 would increase Federal outlays by $1.5 million to $2 million in fiscal year 1989, assuming appropriation of the necessary sums. The bill would not result in any significant costs after 1989.

S. 1295 would amend the Energy Policy and Conservation Act to include fuel cells as a "domestic renewable energy industry" for the purposes of creating new international markets for domestic technologies. In addition, the bill would:

Direct the Secretary of Commerce to assess and report to the Congress concerning the export market potential for integrated systems of fuel cells with renewable power technologies, and

Direct the Administrator of the Environmental Protection Agency (EPA) to prepare environmental and safety guidelines for the use of fuel cells.

Based on information provided by the Department of Commerce and EPA, CBO estimates that preparation of the studies, reports, and guidelines required by S. 1295 will cost $1.5 million to $2 million in fiscal year 1989.

The bill would not have any effect on the budgets of state or local governments.

If you wish further details on this estimate, we will be pleased to provide them. The CBO staff contact is Peter Fontaine, who can be reached at 226–2860.

Sincerely,

James L. Blum,
Acting Director.

Regulatory Impact Evaluation

In compliance with paragraph 11(b) of Rule XXVI of the Standing Rule of the Senate, the Committee makes the following evaluation of the regulatory impact which would be incurred in carrying out S. 1295 as reported.

Sections 3 and 5 require the Secretary of Commerce to report to the Congress with an assessment of potential for export and the identification of any barriers to the export of this technology. The inclusion of fuel cells in the ongoing evaluation of domestic renew-

able energy and related service industries would result in a minimal increase in administrative costs to the Department.

Section 4 increases regulatory authority of the Environmental Protection Agency (EPA) to set environmental and safety standards on fuel cell technology. So far, the development of fuel cell technology has placed major emphasis on the technical and environmental factors. Any new EPA environmental regulations and safety standards could have a strong impact on the direction of future developments.

No personal information would be collected in administering the program, and there would be no impact on personal privacy from S. 1295.

Executive Communications

A legislative report on S. 1295, dated January 29, 1988, was received by the Committee from the Department of Commerce on February 3, 1988.

The Administration testified on the legislation at a hearing before the Subcommittee on Energy Research and Development on September 23, 1987. The written testimony of Assistant Secretary Donna Fitzpatrick is reprinted below.

GENERAL COUNSEL OF THE
UNITED STATES DEPARTMENT OF COMMERCE
Washington, D.C. 20230

1988 FEB -3 AM 9:39

JAN 29 1988

Honorable J. Bennett Johnston
Chairman, Committee on Energy
and Natural Resources
United States Senate
Washington, D.C. 20510

Dear Mr. Chairman:

This is in response to your request for the Department of Commerce's views on S. 1295, a bill,

> "To develop a national policy for the utilization of fuel cell technology."

The bill would amend the Energy Policy and Conservation Act to include within the term "domestic renewable energy industry", those industries using fuel cell technology. It would also require the Administrator of the Environmental Protection Agency to prepare Federal guidelines and safety standards for the use of fuel cell technology, and it would require the Secretary of Commerce to prepare a report to Congress on the export market potential for integrated systems of fuel cells with renewable power technologies.

Section 2 (2) should be changed from "the public investment in fuel cell technology would be realized through reduced dependency on imported oil", to "the public investment in fuel cell technology might be realized through reduced dependency on imported oil", since adopting a national policy for fuel cell technology does not assure the commercial success of that technology.

The export market potential for integrated systems of fuel cells with renewable power technologies depends upon both the capital costs and the operating costs of these technologies as compared to the costs of other available technologies. The Commerce Department does not monitor fuel cell technology because it is not commercially viable at this time. Commercial introduction of fuel cells into the domestic market is probably two to five years away. A meaningful assessment of export potential is unlikely to be had until introduction in the domestic market is under way. For these reasons, we object to Section 5 of the bill, with respect to the requirement that the Secretary of Commerce prepare a report to Congress on the export market potential for integrated systems of fuel cells with renewable power technologies.

We have been advised by the Office of Management and Budget that there is no objection to the submission of this report from the standpoint of the Administration's program.

Sincerely,

Robert H. Brumley
Deputy General Counsel

Statement of

Donna R. Fitzpatrick
Assistant Secretary
for
Conservation and Renewable Energy

U.S. Department of Energy

to the

Senate Committee on Energy and Natural Resources
Subcommittee on Energy Research and Development

September 23, 1987

Mr. Chairman and Members of the Committee:

Thank you for the opportunity to appear before you today to discuss the Department of Energy's hydrogen and advanced fuel cell programs, and the Senate bills S. 1294 and S. 1296 relating to hydrogen and fuel cells.

OVERVIEW ON HYDROGEN

Hydrogen is an abundant element but it does not occur in Nature in the pure state. It has been known to man for about two centuries. It was initially used as a buoyant gas, then as a synthetic-fuel constituent. At present, hydrogen is used almost entirely as a unique industrial chemical in petroleum processing and in synthesis of ammonia and methanol.

In addition to the dominating applications in petroleum refining, ammonia synthesis for fertilizer production, and methanol manufacturing, hydrogen as a chemical has a range of miscellaneous and special uses. Hydrogen is used in the production of foodstuffs, including margarines and cooking fats, and in the manufacture of soap. It serves in the refining of certain metals, in semiconductor manufacture, and for the annealing of metals. It is employed in uranium extraction and processing and for corrosion control in nuclear reactors. Hydrogen also cools electrical generators in utility power stations and is a feedstock in organic

chemical synthesis leading to production of nylon and polyurethane. It is a high energy rocket fuel and an experimental aviation and automotive fuel. The use of hydrogen in each of these applications is quite specialized, but they illustrate the range of industrial uses that already exist.

Hydrogen is not, however, a primary energy source--it must be manufactured. Practically all the hydrogen now produced in this country is manufactured from natural gas and light oils. It must be recognized that as a secondary energy form, the energy to be derived from hydrogen will always be less than the energy required to produce it.

Since hydrogen does not exist on earth in its elemental form, to obtain hydrogen requires conversion of compounds containing hydrogen. This conversion requires energy sources such as coal, solar, or nuclear to be consumed to be able to produce hydrogen. This energy consumption is substantial, currently requiring from 4 to 15 units of raw energy to manufacture 1 unit of hydrogen energy, depending on whether the product is gaseous, liquid, or "slush". Therefore, hydrogen technology represents only a potential bridge between energy sources such as solar, nuclear, and coal and energy consumers such as the various applications mentioned earlier. This is similar to the existing electric power grid or the battery

technologies under development. To determine whether widespread use of hydrogen should take place, the complexities, energy cost, and dollar cost associated with changing our energy production and distribution network must be addressed.

From an energy perspective, the question is not whether the Nation can use hydrogen for many applications now served by electricity or other energy carriers, but should we use it in this way. It is technically possible to connect almost any source to any energy use by means of hydrogen. Our judgment on whether to use this bridge should be governed by the total cost to society. When it becomes more convenient and more economical, it will be used.

RATIONALE FOR HYDROGEN RESEARCH

Today hydrogen can be produced via a number of processes, but it must be remembered that the resulting hydrogen comes from the consumption of other fuel sources and, therefore, cannot be as energy efficient as using the primary fuel. Therefore, if hydrogen is to be used in a greater variety of applications, improvements will be required in several areas to improve the efficiency of hydrogen production. Also, more effective storage systems for both bulk and mobile will be required.

For the production of hydrogen, water electrolysis is the most mature of the water-splitting technologies in use by industry. In DOE sponsored work, advances have been made in electrocatalysis, electrode materials, separators, and electrolytes. Research is still needed to reduce capital cost and maximize reliability for large-scale systems. New developments in water vapor electrolysis conducted at temperatures up to 100 C- promise overall efficiency improvements of 30%-50% over lower temperature water electrolysis technology. Other techniques of water splitting, such as photochemical or biological processes, are infant technologies that show promise for the long term.

Hydrogen can also be produced from coal, natural gas, or renewable sources (wind, ocean). Production from natural gas is the least expensive; costs for other sources can be three to 30 times higher, largely because of the energy consumed by the production process. Therefore, an inexpensive renewable energy source could be the key to the economically competitive production of hydrogen. This suggests that continued research to improve the technology base of renewable energy conversion systems is itself an important step in promoting increased hydrogen use.

Hydrogen storage continues to be a problem. It has been suggested that long-term bulk storage of hydrogen can take place in depleted oil wells and caverns but extensive testing has not been conducted. For mobile applications, metal hydrides -- where hydrogen is temporarily chemically bound to a porous metal matrix -- have been investigated but this form of storage today is an expensive alternative to compressed gas and liquefied hydrogen.

Hydrogen embrittlement of conventional pipeline steels is recognized as a primary deterrent to hydrogen transport at high pressures. Fundamental investigations have verified the embrittlement phenomena and studies have been extended toward identification of embrittlement suppression techniques. Recent investigations have shown that introduction of oxidants as low-concentration additives to hydrogen streams may offer means for suppressing embrittlement.

S. 1296

Let me turn first to specific comments on the Senate bill on hydrogen, specifically Title I of S. 1296, pertaining to the Department of Energy.

The intentions of the bill are good. To prepare for the future is both wise and prudent. This is also the goal of the Department in carrying out its research into ways to produce and

store hydrogen, along with other energy technologies that may serve the same purpose.

As stated, considerable progress has been made in understanding just what is needed to have hydrogen as an alternative energy carrier in the future. Our research is continuing to find improvements in producing, storing, and transporting hydrogen for transportation, process heating, fuel cells, and other applications.

The DOE plans to continue its research and development in hydrogen and believes that the spirit of the proposed legislation can be carried out through its existing program. New legislation is, therefore, not required to accomplish the intent of S. 1296, Particularly in a time of tight budgets, we believe taxpayer dollars are best spent on longer range, more generic research that benefits all areas of hydrogen production, storage, and transportation. Until these fundamental issues are resolved, demonstration and commercialization activities (which are more appropriately the province of the private sector) will not efficiently provide significant progress toward achievement of the objective of S. 1296. Clearly, the Government can provide the most effective contribution by establishing a technology base on which industry can build. Our current hydrogen research has been carefully fashioned to ensure that tax dollars are not supplanting

private sector funding. We will continue to make available to the private sector the results of our technology base research and we will encourage them to exploit this knowledge. The Department of Energy is continuing to expand the range of technical options available to the private sector, including the use of hydrogen, that will improve our Nation's energy future. For these reasons, we do not support this legislation.

I have included in my testimony two attachments, one which further describes the Department of Energy's hydrogen-related research in the Office of Basic Energy Sciences and a second one which elaborates on the Chemical/Hydrogen Energy Storage project in the Office of Energy Storage and Distribution.

Let me turn now to the area of advanced fuel cells, and Senate bill S. 1294 which relates to fuel cells.

OVERVIEW OF ADVANCED FUEL CELLS

The DOE fuel cell program can trace its origins to work that began more than two decades ago in laboratory and special applications research. Today this effort has evolved into a multi-faceted research program. The Office of Conservation and Renewable Energy currently oversees research on Phosphoric Acid fuel cells for transportation applications and manages research on Solid Polymer Electrolyte fuel cells - also known as Proton

Exchange Membrane (PEM) fuel cells. The future application for the latter technology will be predominantly for mobile, and remote.

This multi-pronged effort is internally coordinated, with all elements of the Department exchanging results and future plans on a regular basis.

Technology Descriptions

Fuel cells are energy conversion devices that convert chemical energy directly into electric energy without the inherent efficiency limits of heat engine cycles. A complete fuel cell power plant would typically include a fuel processing section (such as a reformer or a coal gasifier section with gas cleanup), a power producing section (often referred to as the fuel cell stack), and a power processing section with a direct-current-to-alternating current invertor.

Fuel cells are powered by the electrochemical combination of hydrogen and oxygen. The source of hydrogen can vary considerably; virtually any hydrocarbon fuel can be a potential feedstock for a fuel cell power plant, although for economic reasons, coal, natural gas, other sources of methane and methanol will likely be the principal fuels.

Higher operating temperatures may provide significant efficiency and capital cost advantages; however, elevated temperatures are not suitable for all potential fuel cell applications. In particular, the choice of a fuel cell for some mobile applications may be dictated, in large part, by the need for a system capable of operating at reduced temperatures, i.e., the phosphoric acid or proton-exchange-membrane technology. Other concepts in the very early development phases (such as the monolithic solid-oxide concept) may offer low-weight and low-volume systems compatible with some mobile applications.

Applications and Research Emphasis

Programs are in progress at Brookhaven National Laboratory and at Los Alamos National Laboratory (LANL) for the investigation of fuel cells for vehicular propulsion. Some of the above advantages of fuel cell power plants over thermal ones for electric and gas utility power generation apply equally well for vehicular power plants. The significant one is that the projected efficiencies for fuel cells are at least twice as high as those for internal combustion and diesel engines.

Transportation's share of petroleum use in the United States reached 64% in 1986. This figure represents 108% of domestic production and indicates the impact that changes in the transportation area can have on petroleum needs. The objective of the fuel cell work at LANL is to help reduce U.S. dependency on petroleum resources and to provide full performance vehicles. Fuel cells possess a number of attributes that make them very attractive for transportation applications. Their high efficiency and ability to use non-petroleum fuels address the petroleum dependency problem. Their operational simplicity, safety, and low pollution are features that make them desirable for use in cars and trucks. The fuel cell system chosen for a given application must be selected on the basis of performance and of type of fuel required. Based on the state-of-development, fuel considerations, and the inherent restrictions imposed by vehicular applications, only acid fuel cells, phosphoric acid (PA) and proton exchange membrane (PEM), operating on reformed methanol and air are being considered at the present time. The PA fuel cell is the choice for near-term use, because it represents the only technology that has demonstrated full-stack operation on reformed fuel. The potential of the PEM fuel cell in terms of high power density, low-temperature operation, rigid and contained electrolyte, and cold start capability dictated its consideration, even though the system technology development is immature for terrestrial operation on reformed fuel.

In summary, simulation studies indicate that it is feasible to use fuel cell or fuel cell/battery hybrids in city buses and in passenger cars. Improvements in technology should enhance this feasibility of using fuel cells in transportation. Fuel cell use in the transportation sector will depend upon the success of ongoing research efforts to overcome constraints on cost, size, and operating conditions.

Another area of fuel cell application, sponsored by the American Gas Association, is the residential and commercial buildings sector. Strong interest by the gas utilities is evidenced by the recently completed field test of nearly fifty 40-kilowatt power plants producing electricity and cogenerated heat. Introduction of commercial gas-using fuel cells in this sector is expected in the 1990s. Due to the smaller size required of fuel cell power plants for the residential sector, (several kW), and also because of competitive economic constraints, fuel cells are unlikely to find application in the residential sector in the immediate future. Use of feedstocks such as coal or biomass in these applications will likely depend upon the economic competitiveness of processes to convert these fuels into pumpable gaseous or liquid products and the existence of suitable delivery systems.

Fuel cell use in the industrial sector could follow introduction in the electric utility sector and basically rely on modules similar to those being developed for electric utility plants.

Renewable Fuel Cell Program

Solid Polymer Electrolyte Fuel Cell Systems: This system is being considered for transportation applications. Because the system operates at less than 100 C, methanol is the most appropriate liquid fuel to be reformed and used in this fuel cell system. Progress had been made at Los Alamos National Laboratory to reduce the noble metal, e.g., platinum, loading to one-tenth that of the previous state-of-the-art system. This is done by incorporating a proton conductor into the electrode structure to extend the three-dimensional reactor zone. Water management can be achieved by optimum humidification of the system. Prospects are good for attaining high power densities (those over 500 mW/cm^2).

Direct Methanol Fuel Cell: A fuel cell researcher's dream is to oxidize organic fuels (preferably methanol, which can be produced from biomass or coal) rather than to process these to hydrogen, which is, in turn, oxidized in the electrochemical cell. Methanol is the most active electro-organic fuel, but its activity is 3 orders-of-magnitude less than that of hydrogen. Thus, under these conditions, current-densities of about 50 mA/cm^2 are obtained at cell potentials of 0.4 V, somewhat lower than desired. Even at these current densities, there is a performance degradation with time. The main cause for the degradation is that the intermediates formed during methanol oxidation poison the platinum electrocatalyst. The poisoning effects are less with some alloy electrocatalysts (e.g., Pt-Ru, Pt-Sn) and with platinum electrocatalysts with additional atoms such as Bi, Pb, Sn, Ge.

Prognosis of Economics and Applications of Fuel Cell Systems

The applications of fuel cell systems have been well-demonstrated in space vehicles. Capital costs are not such an overriding factor for space applications as they are for terrestrial applications. The alkaline, and possibly the solid polymer electrolyte fuel cell, systems will continue to be the auxiliary power sources for space vehicles. The present price of crude oil makes it more difficult to introduce fuel cell systems

into the terrestrial arena. On the other hand, environmental constraints can also accelerate the entry of fuel cell technologies.

The bottom line with respect to economics of fuel cells for terrestrial applications will be the cost of electricity generated, which, in turn, will depend on capital costs, efficiency, and life-time. Taking into consideration the performances of fuel cells for terrestrial applications, the major factors to be overcome are: (1) development of automated techniques to reduce the capital costs of the system; (2) achievement of reliability of performance over the required lifetimes; (3) demonstration of economic, technical, and environmental advantages of dispersed, on-site integrated energy and cogeneration power plants; and (4) development of a niche for electric vehicles - in plants, military uses, buses, trucks, and automobiles.

The factors that impede the commercialization of fuel cells are that improvements are needed in the areas of initial cost, lifetime and performance. More specific barriers are the high cost of electrocatalysts and porous electrodes; the corrosion of active and passive cell components; instabilities of porous electrode

structure under long-term cycling; loss of electrocatalytic activity with time and use; inadequate conductivity of electrolytes for high-performance (power) application and lack of advanced electrodes and cell-designs for high-performance applications. By addressing these issues the DOE programs will improve the base technology to the point where industry can develop commercial prototypes.

S. 1294

The purpose of the bill, stated as "exploring the operation of fuel cells employing methane gas generated from various forms of biomass", will be a good match with the type of fuel cell and fuel processor being developed. The focus is on solid polymer electrolyte fuel cells, because they offer the potential for higher power density fuel cells; they tolerate carbon dioxide in the fuel streams, and therefore can use reformed methane, methanol, or

hydrogen; and they operate below one-hundred degrees centigrade, allowing low temperature startup and use of low-cost structural material. The operation of cells on reformed methanol and hydrogen is currently being investigated and the prototype fuel cells will also be tested with reformed methane.

As I have explained, production of hydrogen by water electrolysis and photoelectrochemical methods are part of the hydrogen program. Hydrogen is currently used as a fuel cell fuel. Currently there are no activities related to the third purpose of the bill, "determining the technical requirements for employing fuel cells for power production as backup spinning reserve components to renewable power systems in rural and isolated areas." This is an area that should be carried out in the future but currently has a low priority because of the immaturity of the technology.

Where government can provide the most effective contribution to fuel cell technology is in building a solid base of technological information which industry can use to make market-oriented, developmental decisions.

Our current fuel cell program, particularly as it is presented within the President's Fiscal Year 1988 budget request, has been carefully fashioned to ensure that tax dollars are not supplanting private sector funding. We will continue to make available to the private sector the results of our technology base research and will encourage them to implement this research when market forces dictate.

The Department of Energy is committed to expanding the range of technical options available to the private sector that will improve our Nation's energy future; fuel cells are a sound prospect for this future. Current programs are adequately funded to address the intent of these bills. Any future activities will be considered as part of the budget process. For this reason, we do not think this legislation is necessary. As I indicted previously, the remaining pages of our testimony provide more details on the ongoing fuel cell efforts with the Department of Energy.

Thank you for the opportunity to discuss this area of research with you today.

ATTACHMENT 1

HYDROGEN-RELATED RESEARCH

The Office of Basic Energy Sciences (BES) supports long-range basic energy-related research and is charged with providing the fundamental scientific foundation for the Nation's future energy options. Accordingly, some of the 1400 individual research projects in the areas of physical and biological sciences, engineering, and geosciences are related to DOE's interests in hydrogen. The hydrogen-related research supported by BES is found largely in the divisions of Chemical Sciences, Materials Sciences, and Energy Biosciences. In almost all cases, the research is long range and generic with very little research being focused directly on a specific energy technology.

The Chemical Sciences research includes basic solar photochemistry, biomass chemistry related to dissociation of water, and hydride research for the storage of hydrogen. The focus of the Chemical Sciences programs as it relates to hydrogen is on the fundamental understanding of the chemistry involved in production and storage concepts at the most basic level.

In our fundamental research program in solar photochemistry energy conversion, fundamental processes are being explored which can be applied to hydrogen production by splitting the water molecule into its components, hydrogen and oxygen, to methanol production from carbon dioxide, ammonia synthesis from atmospheric nitrogen, or to production of other needed chemicals at lower energy cost by using sunlight. The research is expected to provide the basis for new solar chemical technologies in the distant future.

Solar photochemistry research is proceeding on several fronts. In plant and bacterial photosynthesis research, the emphasis is on understanding how sunlight initiates the primary steps of photosynthesis at the molecular level. This insight is being used to design simple molecules which can absorb light and use its energy to separate charges long enough to drive useful chemical reactions. Other research involves photocatalytic chemical reactions in homogeneous and heteorogeneous systems. Particularly noteworthy in this area are metal catalyst-coated semiconductor colloidal particles in solution, where product separation may be achieved by vesicles or bilayer membranes. Other reaction systems involve photosensitization by porphyrins or other visible light-absorbing chromophores. The key to success in the design of these systems is more efficient electron transfer in the forward direction than the reverse, which necessitates careful mechanistic and kinetic experiments. Photoelectrochemistry is perhaps the most

advanced area of solar photochemistry research, although no known semiconductor is the perfect candidate. Semiconductor electrodes which absorb in the visible region must be protected from photocorrosion in aqueous solution, which is being achieved by coatings of transparent conducting polymers. Other semiconductors which are photostable in water but absorb outside the visible region are being modified with pendant chromophores photocatalysts to drive the chemical reactions of interest.

Other efforts in chemical sciences include the study of photosynthetic evolution of hydrogen from biomass systems using enzyme catalytic processes and the chemical aspects of hydrogen storage in hydride systems. The latter includes the determination of thermochemical properties and structural parameters to understand their behavior on hydriding characteristics.

The Materials Sciences programs related to hydrogen are focused on obtaining a fundamental understanding of the interactions of hydrogen with materials. These programs are, therefore, necessarily basic or generic in character and do not directly engage in the development of specific technologies for a hydrogen economy. They do, however, provide fundamental understanding necessary for the development of these and other related technologies; for example, technologies related to hydrogen storage, end-use, and synfuel production. Specifically, research is underway on diffusion of hydrogen in rare earth, on refractory

metal alloys, on the uptake and the thermodynamics and kinetics of hydrogen in noble metals, on behavior of hydrogen on metal surfaces, on a theoretical understanding of the effects of hydrogen on bonding in metals, on hydrogen attack, on a phenomenon that occurs in some steels subjected to high-temperature, high-pressure hydrogen as a coal gasification process, and on protonic conduction in solid electrolytes as might be encountered in batteries or fuel cells.

The Division of Energy Biosciences supports research aimed at understanding the mechanisms involved in the biological production and utilization of molecular hydrogen. The long-term objective of the program is to provide the requisite scientific foundation for the development of novel biotechnologies based on hydrogen as an energy resource or ones in which hydrogen plays an integral role in the production of other products such as methane. The emphasis of the research supported is on the bioenergetics of hydrogen production and the enzymes, the hydrogenases, responsible for the production of hydrogen driven by light energy directly or indirectly through renewable plant resources. The related hydrogenases responsible for the transfer of hydrogen between species of anaerobic bacteria is also a research area supported. Effort also focuses on understanding the group of enzymes which are responsible for hydrogen production, hydrogen transfer, or hydrogen

utilization. Their molecular structure, genetic and metabolic regulation mechanism of action, oxygen liability, and involvement of metals are all subjects of investigation.

ATTACHMENT 2

CHEMICAL/HYDROGEN ENERGY STORAGE PROGRAM

Background

For the past decade, DOE has pursued mission-oriented hydrogen technology development. These programs concentrate on long-term technology-base developments geared to conversion, storage, and transport.

PROGRAM RATIONALE AND STRATEGY

Chemical/hydrogen energy systems (C/HES) are identified as a candidate link between renewable primary resources and energy demand sectors. Current economics and the availability of conventional energy resources place the exercise of the C/HES option well into the far term. Therefore, a long-range program has been structured to develop a technology base across the full spectrum of conversion/production, storage, and transport technologies. The R&D investment is viewed as increasing the flexibility to accommodate a different mix of energy supply sources in the future.

Cost Performance Objectives

The versatility of hydrogen as a fuel and chemical commodity and its environmentally benign characteristics have been well documented. It remains for a technology base to be developed which

will effectively establish cost effective benefits. Conversion of various resources to a secondary chemical energy form, such as hydrogen, calls for achieving high conversion efficiencies at minimal capital outlay. Effective storage of this chemical energy in bulk and mobile systems is required to offset energy supply-demand mismatches and to provide on-board energy storage options for vehicular transport.

The conversion, storage, and transport requirements have been translated to specific cost and performance objectives for each element of the program.

- o Hydrogen Production Cost -- $10/MMBtu (1980 dollars)
- o Storage Cost ---------- $1-3/MMBtu (1980 dollars)
- o Storage Density ---------- Greater than 4% by weight for metal hydrides or 2500 BTU's per lb.
- o Transport ---------- Long-Term Stability (conventional pipeline)

Technology State-of-the-Art

Hydrogen Production - Historically, this segment of the program has been concerned with developing alternatives to steam reforming of natural gas for the production of hydrogen, with emphasis placed

mainly on the dissociation of water via electrolysis. Energy used for dissociating water can be in the form of heat or electricity. Since Carnot limitations of steam cycles used to produce electricity imply an efficiency ceiling, it would appear prudent to pursue the direct utilization of heat in water-splitting processes. Thermal decomposition processes operating in the extreme temperature regimes (greater than 3000 C) do not bode well with regard to materials availability and process simplicity. Substantial efforts in the past have been directed toward identifying thermochemical cycles which could alleviate some of the process engineering difficulties; however, materials handling, corrosion, and process complexity remain major problems.

Technical judgments suggest that a combination of thermal and electrochemical processes can be optimized via development of high-temperature (300C-1000C) water vapor dissociation. Such systems can result in overall energy efficiencies approaching 50%.

Determining the cost of producing this hydrogen is not a simple matter. This cost depends upon the cost of electricity (peak or offpeak), capital cost, and utilization factor. As a rule of thumb, hydrogen can be produced from natural gas for about $6-9/MMBtu. Electrolytic hydrogen can be produced for about $15-25/MMBtu. Due to the uncertainties in electricity cost, utilization factor, and capital costs, it is difficult to project future markets for hydrogen.

Hydrogen Storage - Current practice relies on compressed gas or liquefied hydrogen as the primary storage options. These storage systems do not lend themselves to bulk long-term or mobile short-term storage applications necessary if hydrogen is to assume an expanded role in the future U.S. energy infrastructure.

Substantial efforts in the U.S. and abroad toward advancing hydrogen storage technology have been only moderately successful. Various metal hydrides based typically on iron-titanium and magnesium alloys have been characterized and found wanting with regard to cost, weight/volume storage density, or required operating temperature/pressure regimes. Cryoadsorption of hydrogen in carbon at liquid nitrogen temperatures has been explored to some extent in Europe. DOE has supported R&D in advanced hydrides and in microcavities as hydrogen storage media.

Hydrogen Transport - Supplementation of natural gas with hydrogen is one option under consideration for future energy systems. Assuming efficient conversion of a given primary resource to hydrogen, some savings over electric energy transmission potentially could be realized if this energy were transported by pipeline. These are: reduced transmission losses limited to pressure drop and leakage compared to impedance losses, reduced capital cost of pipe compared to power transmission lines, reduced costs of right-of-way. To use this option, it is necessary to establish the compatibility of hydrogen with conventional pipeline

steels. Protective measures for ensuring the safe and effective transport of hydrogen via available pipelines would require research.

HYDROGEN ACCOMPLISHMENTS AND FUTURE NEEDS

Accomplishments over the past decade derived from the hydrogen component of the C/HES program are summarized:

- Solid Polymer Electrolyte (SPE) Water Electrolysis System--General Electric - Comprehensive R&D program culminated in the fabrication and test of a 200-kW system which approached high efficiency and cost goals. Another smaller 20-kW unit demonstrated reliable on-site production of hydrogen which was used for utility electric generator cooling. Technology subsequently sold to Hamilton-Standard which is currently pursuing commercial prospects.

- Static Feed Water Electrolysis--Life Systems, Inc. - Multicell (1 ft) module designed, fabricated, and tested, demonstrates the ability to electrolyze brackish water and sea water. The system eliminates need for electrolyte circulating pump as well as water treatment subsystem, thus maximizing reliability and permitting low-cost manufacturing of molded parts. Technology was

transferred to NASA-supported programs in Orbital Space Station Storage systems.

- Advanced Alkaline Water Electrolysis--Teledyne Energy Systems - Modest R&D program was able to demonstrate substantial improvements in electrolyzer elements (electrodes, catalysts, structural components). Limited success in separator development which would have permitted higher temperature (125-150C) operation.

- Underground Storage--IGT - Comprehensive engineering analyses show feasibility and problems of long-term storage in depleted wells and in caverns.

- Metal Hydride Storage - A wide range of alloys prepared and tested to show a safe alternative to compressed gas and liquefied hydrogen storage. Studies have shown, however, that low-cost, high-storage-density materials require high temperature for hydrogen release. On the other hand, low-temperature materials exhibit low storage densities and high cost.

- Rapid Cycling Applications (Metal Hydrides) - Chemical compressors in early states of commercialization. Metal hydride pair chemical heat pump proved viable for heating and cooling. Hydrogen separation/purification

shown to be an alternative to pressure-swing adsorption and cryogenic separation.

- Hydrogen Transport/Transmission - Long-term program initiated by Sandia and completed by Battelle Laboratories fully characterized key problems of hydrogen embrittlement in pipeline steels. Battelle also demonstrated that additive gases (inhibitors) eliminate a number of the embrittlement problems.

- Hydrogen Technology Evaluation Center (HTEC) - Brookhaven National Laboratory facility was used to demonstrate the characteristics of interfacing an advanced technology electrolyzer with a photovoltaic system for hydrogen production, with coupling to electric grid. The facility was also used to conduct a performance mapping of a metal hydride compressor operating in both the closed and open loop modes. Test programs provided an opportunity for training/technology transfer involving representatives from MIT, Florida Solar Energy Center, EPRI, Public Service Electric and Gas Company of New Jersey, and the University of Hawaii.

Ongoing R&D activities are briefly described:

- A study examining the potential of hydrogen derived from renewable energy sources is continuing. In this effort, the status of current renewable hydrogen technology will be compared with conventional hydrogen production and areas where additional research might result in significant improvements will be identified. The ability of an energy infrastructure to assimilate greater hydrogen usage will be addressed, using Hawaii as the model. A major hydrogen application derives from benefits in increasing the hydrogen/carbon ratio of biomass to produce liquid fuels, e.g., methanol.

- A major program is being conducted by Westinghouse developing their thin film solid oxide technology for high-temperature water vapor electrolysis applications. Cell testing has shown performance in the 1.3 V range at current densities of 300 A/ft^2, and also conversion of up to 90% of steam to hydrogen and oxygen. A comprehensive theoretical model of vapor electrolysis is being developed which will provide information to improve performance.

- Several activities are underway investigating medium-temperature electrolysis in the 300-600 C temperature range. Brookhaven National Laboratory and Politecnico di Milano have recently completed characterization of aluminum phosphate and barium sulfate as "unsuccessful" candidate materials. In a parallel investigation the University of Pennsylvania has examined the use of beta alumina as a proton-conducting material suitable for medium-temperature electrolysis. Data have been obtained on thermal stability and conductivity as a function of water vapor pressure. Subsequent to a competitive procurement, Stanford University has identified a novel hydrogen ion conducting electrolyte which may provide a basis for a successful intermediate temperature range water vapor electrolysis system. Further, this electrolyte may serve to enhance prospects for using low cost hydrides as hydrogen storage media via the electrochemically - assisted dehydriding reaction.

- Battelle Columbus is addressing a novel approach to photolytic hydrogen production making use of plasma/polymer-coated semiconductor electrodes. Progress has been made in optimizing stability, optical transparency, and electrochemical cell characteristics.

- A key program in hydrogen storage is going on at Syracuse University attempting to make use of catalyzed, activated carbon to store hydrogen at low temperatures suitable for use in mobile/stationary applications. Adequate storage has been demonstrated on the macro scale but only at very low liquid nitrogen temperatures. Current work is investigating higher pressure, higher temperature operation, and alternate carbon materials. A class of super-activated carbons treated to provide high surface acidity has been found to satisfy 4% by weight system requirements at temperatures of 150 K (liquid freon temperatures).

CHANGES IN EXISTING LAW

In compliance with paragraph 12 of Rule XXVI of the Standing Rules of the Senate, the Committee notes the following changes in existing law made by the bill as reported (existing law proposed to be omitted is enclosed in black brackets, new matter is printed in italic, and existing law in which no change is proposed is shown in roman):

ENERGY POLICY AND CONSERVATION ACT, PUBLIC LAW 94-163, AS AMENDED

* * * * * * *

DOMESTIC RENEWABLE ENERGY INDUSTRY AND RELATED SERVICE INDUSTRIES

SEC. 256. (a) It is the purpose of this section to implement the responsibilities of the United States under chapter VII of the international energy program with respect to development of alternative energy by facilitating the overall abilities of the domestic renewable energy industry and related service industries to create new markets.

(b)(1) Before the later of—

(A) 6 months after the date of the enactment of this section, and

(B) May 31, 1985, the Secretary of Commerce shall conduct an evaluation regarding the domestic renewable energy industry and related service industries and submit a report of his findings to the Congress.

(2) Such evaluation shall include—

(A) an assessment of the technical and commercial status of the domestic renewable energy industry and related service industries in domestic and foreign markets;

(B) an assessment of the Federal Government's activities affecting commerce in the domestic renewable energy industry and related service industries and in consolidating and coordinating such activities within the Federal Government; and

(C) an assessment of the aspects of the domestic renewable energy industry and related service industries in which improvements must be made to increase the international commercialization of such industry.

(c)(1) On the basis of the evaluation under subsection (b), the Secretary of Commerce shall, consistent with existing law, establish a program for enhancing commerce in renewable energy technologies and consolidating or coordinating existing activities for such purpose.

(2) Such program shall provide for—

(A) the broadening of the participation by the domestic renewable energy industry and related industries in such activities.

(B) the promotion of the domestic renewable energy industry and related service industries on a worldwide basis;

(C) the participation by the Federal Government and the domestic renewable energy industry and related service industries in international standard-setting activities; and

(D) the establishment of an information program under which—

(i) technical information about the domestic renewable energy industry and related service industries shall be provided to appropriate public and private officials engaged in commerce, and

(ii) marketing information about export opportunities shall be available to the domestic renewable energy industry and related service industries.

(3) Necessary funds required for carrying out such program shall be requested in connection with fiscal year beginning after September 30, 1984.

(d) There shall be established an interagency working group which, in consultation with the representative industry groups and relevant agency heads, shall make recommendations to coordinate the actions and programs of the Federal Government affecting commerce in renewable energy products and related services. The Secretary of Energy shall be the chairman of such group. The heads of appropriate agencies may detail such personnel and may furnish such services to such working groups, with or without reimbursement, as may be necessary to carry out its functions.

(e) For purposes of this section, the term "domestic renewable energy industry" shall include industries using fuel cell technology.

○